INDIAN METEORITES

GEOLOGICAL SURVEY OF INDIA
2014

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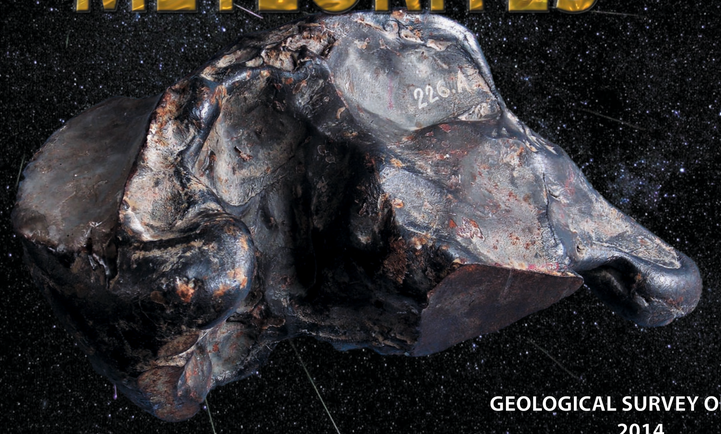

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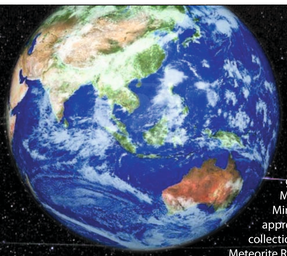

Acknowledgements

The idea of bringing out a coffee table book on meteorites was germinated by Shri D.S. Mishra, Joint Secretary, Ministry of Mines, while appreciating the rare collections maintained at the GSI Meteorite Repository at Kolkata during his visit on 8th February 2013. He inspired the GSI team to publish a popular edition of pictorial representation of Indian meteorites for the people at large. His keen interest and encouragement are gratefully acknowledged.

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Director General

GEOLOGICAL SURVEY OF INDIA

INDIAN METEORITES

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Preface

Meteorites, the extraterrestrial rock pieces, arrive from parts of the solar system packed with wealth of information on the creation of our mother earth and the solar system as well. These priceless heavenly gifts are considered as "poor man's space probe", the opportunity which scientists get without the help of any astronaut.

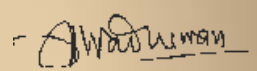
It took thousands of years to change over from myths on shooting or falling stars to scientific acceptance of meteorite as the most valuable planetary rock on earth. In fact, these are those part of rocks in our solar system which neither could be planets nor a part of the existing ones but remain orbiting around the sun or in the inner solar system, between Mars and Jupiter. The study of meteorites leads to the evolution history of the solar system, nearly 4.6 billion years ago.

Since inception of the Geological Survey of India, Thomas Oldham, the founder Director, took interest in collection of meteorites from the private collectors and displayed in the gallery of Indian Museum in Calcutta. He also started systematic cataloguing the meteorites. GSI is the authorized curator and repository of all the meteorites fall on the Indian soil and presently possesses about 700 meteorites of different kinds.

Geological Survey of India has been the custodian for all meteorite "falls" or "finds" within Indian Territory and it has conserved the Indian meteorites for scientific researches as well as for posterity. Each milligram of meteorite sample is invaluable, as the answer to the very question of "our origin" perhaps lies within such meteorites. Every meteorite is, to a great extent, unique in its own way and demands extreme urgency and awareness in matters of collection and proper preservation.

This coffee table book publication is aimed to arouse curiosity as well as to answer a curious mind. This has been attempted with an introductory chapter followed by pictorial depiction of some selected Indian meteorites of different types to sensitise the people of scientific back-ground of the meteorite, the extraterrestrial objects behind the fantasies of shooting star .

I sincerely hope that this publication will increase awareness on the importance of meteorites, its study and its conservation as well as it will answer some basic questions on meteorites. Endeavour of the Mission-III and Mission-IV deserves to be appreciated, particularly the Publication Division, Petrology Division and Curatorial Division of Central Headquarters to have made an attempt to bring out such an informative document that will provide the reader a synoptic view of the Meteorite Gallery of GSI. Hope this book will gain popularity among the public and earth scientists.



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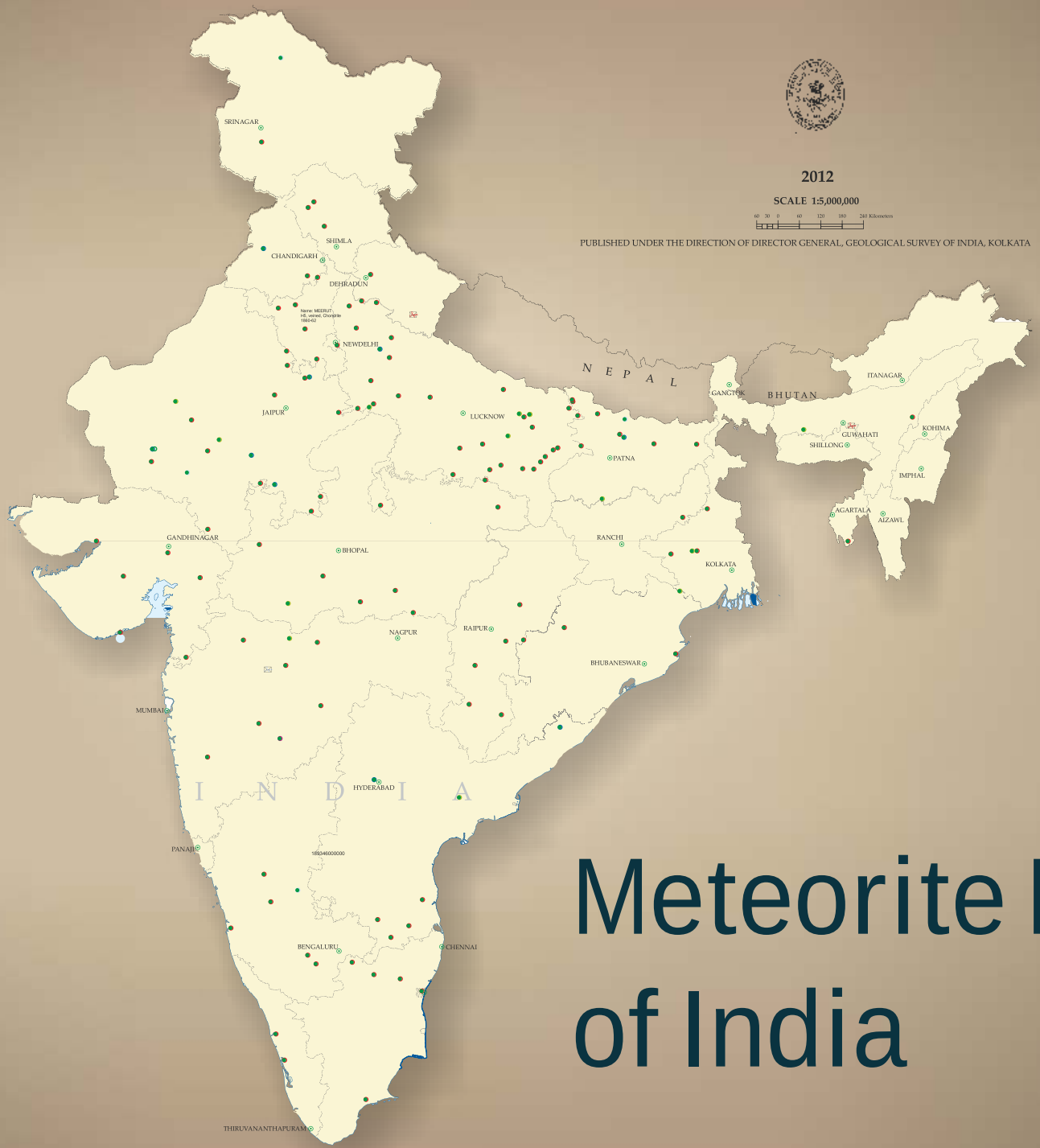
Director General
Geological Survey of India


Prologue



Meteorite Map of India

Since time immemorial Man has been fascinated by shooting stars in the starlit nights. Throughout the globe myths and stories, verses and tales have been written and told on these shooting stars through thousands of years. Then man got awed to see these shooting stars to come down towards earth's surface at a great speed like a bright fireball and to fall on the ground. It was taken to understand that these had fallen to the earth from the abode of deities. This was also the source of cultish worship. Although the use of the metal found in meteorites also is recorded in myths of many countries and cultures where the celestial source often was acknowledged, scientific documentation only began in the last few centuries.

The German philosopher, Chladni, first induced scientific men to investigate these non-terrestrial objects. As the number of 'finds' and 'falls' of such stones were being recorded from across the globe the scientists unanimously agreed upon the fact that the falling of these stones were from the sky. These objects from the sky are meteorites. Scientific interest grew gradually on meteorites. They were objects of interest primarily for geologists. Detailed study and laboratory examinations have uncovered the mystery on the formation of meteorites that unravel in turn the origin of our solar system.

The importance of collection and systematic cataloguing of meteorites was felt in the nineteenth century. Like many museums of natural history and science, Geological Survey of India (GSI) displayed its collection in the gallery of the Indian Museum in Calcutta. It initiated with the purchase of entire meteorite collection of Professor Robert Philip Greg by the Government of India in 1865.

In 1867, Thomas Oldham, the first Director of GSI made the third catalogue with 258 falls and finds in the series of collections and published; the first catalogue was prepared by him only in 1864 with collections of 21 stony and 26 iron meteorites. In 1868, these were amalgamated with the specimens under the possession of the Asiatic Society of Bengal and later augmented by Indian falls officially receive and by donations and exchanges. The combined collection of 296 specimens was rearranged and catalogued in 1879-80 through an excellent publication *Popular guide to the Geological Collections in the Indian Museum*, Calcutta, No.3, Meteorites by F. Fedden of GSI. J. Coggin Brown introduced a descriptive catalogue of meteorites in the possession of GSI in a GSI Memoir (Vol.43) in 1916. A.L. Coulson published a GSI Memoir (Vol.75, 1940) cataloguing 1258 meteorites collected till August 1, 1939. This was later updated by M.V.N. Murthy et al in 1969 and P. R. Sengupta and S. Sengupta in 1982. Pictorial catalogue of selective one hundred meteorites belonging to different chemical groups and petrological types is the first of its kind published by GSI in 1999 under the authorship of S. Ghosh and A. Dube.

With the explosion of new technologies in disseminating scientific information through different audio-visual media, in many an exposition of GSI's exhibition pavilion requests are recorded to produce a popular edition on meteorite to move the people from the myths of shooting star to the scientific evidence of origin of our solar system. This popular manifestation of pictorial documentation on representative Indian Meteorites is an humble response from a responsible organization.

Editor

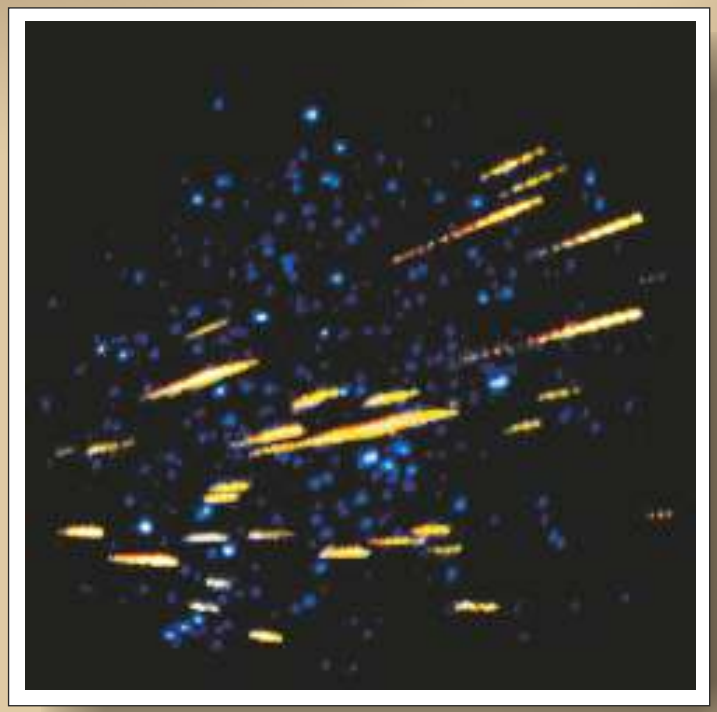


Fig.1. Meteor Shower
(photo source: Internet)

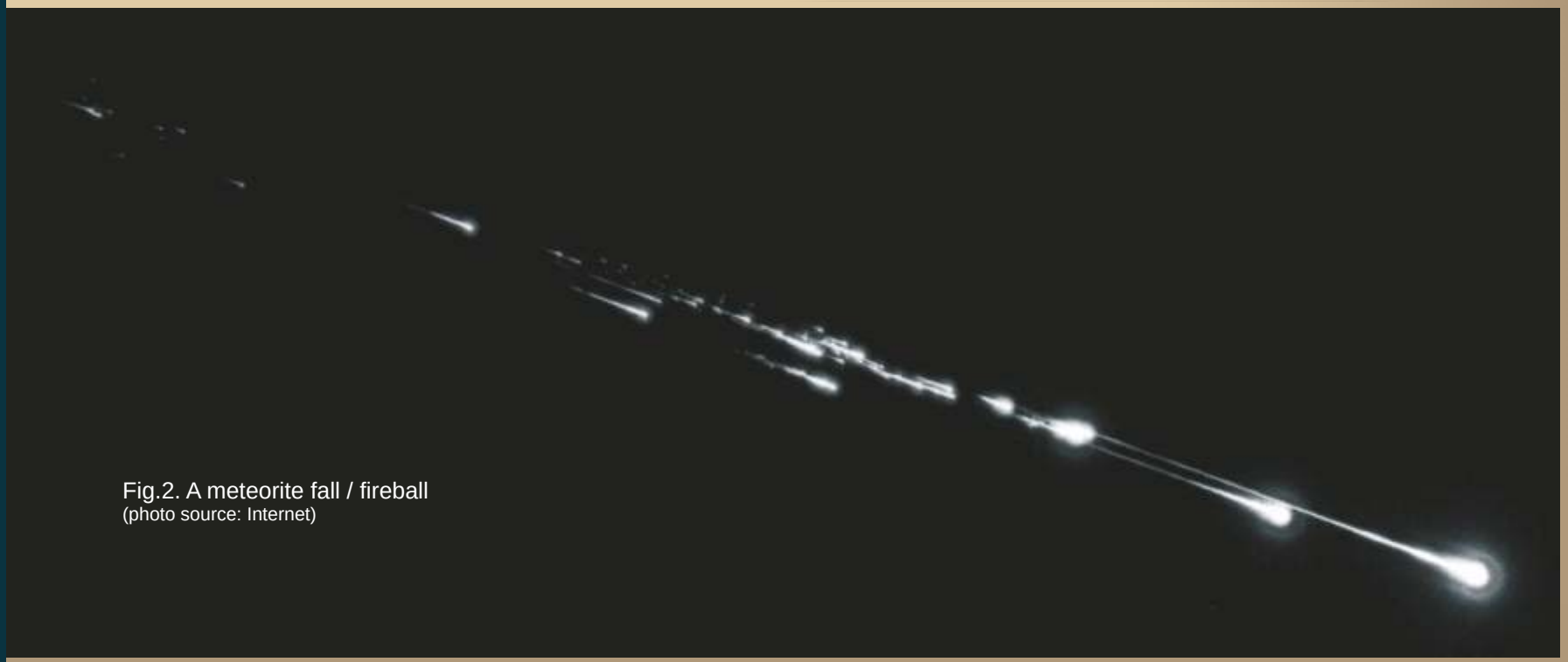


Fig.2. A meteorite fall / fireball
(photo source: Internet)

Meteorite and Indian meteorites

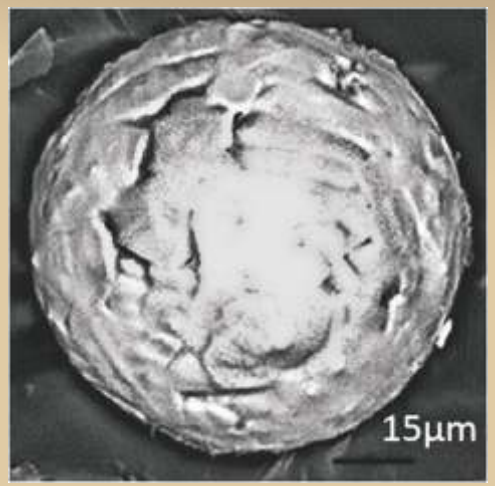


Fig. 3. Micrometeorite
(photo source: Internet)

Fig. 4. Meteorite

What are Meteorites?

Meteorites are natural objects which arrive from outer space and land on Earth's surface surviving the atmospheric friction and impact. This may be a piece of a meteoroid orbiting around the Sun, or a larger object asteroid orbiting in the inner solar system, or a piece of Moon or of Mars. Further smaller particles are interplanetary dust.

A meteor is a visible streak of light generated due to friction when an asteroid or a meteoroid enters the Earth's atmosphere. It moves rapidly across the sky, popularly called shooting star or falling star. Sometimes hundreds of meteors are sighted in a particular night and this show of light is termed as meteor shower (Fig.1).

A brighter-than-usual meteor is called fireball (fig.2), sometimes with thunderous noise termed sonic boom.

The smallest meteoroid which survives to fall on earth is known as micrometeorite (Fig.3) or cosmic spherule and the larger and tougher one survive as a meteorite (Fig.4).

SHERGOTTY

Fig.5. Meteorite from Mars fell at Shergotty in Gaya of Bihar on 25th August 1865; smooth well rounded edges, glossy net-like fusion crust.

Location :	**Bihar, Gaya, Shergotty, 24˚33'00" N : 84˚50'00" E**
Date & Time of Fall/Find :	Fall 25-08-1865 ; 09:00:00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	3553.80 g : 14.2 X 13.1 X 12.0 cm^3
Specific Gravity :	3.28
Classification:	Shergottite Achondrite

Where from meteorites come into the Earth?

Most meteorites appear to come from asteroid belt lying in the region between Mars and Jupiter and were formed early in the history of the solar system ~4.56 billion years ago. Thus most of these meteorites are older than our Earth. However, non-asteroid meteorites also hit the earth but in very small number. Some of them are from Mars (Martian Meteorite; Fig.5) and a few from the Moon (Lunar Meteorite). Both originated almost at the same time with Earth. Meteorites may even come from the comets also.

A question may arise that how meteorites come from these asteroids or from Mars or Moon? Due to impact of a large meteorite on an asteroid body, a piece of it is ejected at ease because of absence of atmosphere and very low gravity and by chance when this piece of asteroid comes within the orbital path of the Earth, we may get a meteorite fall by pull of gravity. Mars and Moon have either very thin (Mars) or no atmosphere (Moon) and low pull of gravity. This makes easy to eject a piece of these planetary bodies when a larger meteorite impact occur on Mars or Moon.

Why meteorites are so important and valuable?

The meteorites provide some of the rarest original materials from which the entire Earth was formed. It also offers clue to formation of our solar system. This along with their scarcity makes these heavenly objects most sought after by scientists.

Fig.6. Largest reported meteorite of the world, Hoba Iron meteorite, Namibia
(photo source: Internet)

Thank God! Earth has an atmosphere

A meteorite may fall on the Earth's surface as a single object or a large meteorite may break up into fragments due to impact with atmosphere , which may be few or a few hundred in number. This is termed as meteorite shower. If a large meteorite does not break up in the atmosphere, it hits the earth with a great collision and produce impact or explosion crater depending on the mass of the meteorite. Thankfully, most of the large meteorites are fragmented due to impact with atmosphere.

Tektite is a glassy terrestrial object, which may form due to a large impact of meteorites and itself is not a meteorite.

World's Largest Meteorite Fall

Hoba Iron meteorite (Fig.6), Namibia is the single largest known meteorite in the world. Original estimated weight is about 100 tonnes.

Largest Fall in India

The largest meteorite fall recorded in India is Sulagiri stony meteorite (Fig.7) on 12th September, 2008 in Tamil Nadu. It fragmented into several pieces, making a meteorite shower with a total weight of > 150 kg over an area of about 5.7 sq km. The area across which the meteorite shower occurs is known as a strewn field. Here the meteorites fell in an elliptical shaped strewn field. The meteorites fell in the morning hours over a span of one hour. The fragmentation happened in the atmosphere with a thundering sound heard by the villagers.

Meteorite fell into pieces

A piece of the Sulagiri Meteorite

Fig.7. Meteorite fall in Sulagiri, Tamil Nadu

Explosion or impact crater

An impact crater is produced when a moderately large meteorite hit the earth. In case of a huge meteorite, the impact would be so high that the whole meteorite could be vapourized and a catastrophic event may occur. Depending on the size of the meteorite the size of the crater may vary from small to very large. Arizona Crater in USA (Fig.8) and Lonar Crater in India (Fig.9), are such impact craters.

The dimensions of the largest impact crater happened in Tamil Nadu in 2008 is 160 cm x 143 cm x 90 cm.

Many smaller craters (Fig.10) also developed due to impact of smaller meteorites.

In Katol, Maharashtra meteorite shower happened in the night of 22nd May 2012. A sudden appearance of light at a high speed crashed on the Earth. A smaller piece made a hole in the tin roof of a house (Fig.11) and another piece made a crater on the floor.

Fig.8. Arizona crater, USA is believed to have formed from the impact of a large iron meteorite 50,000 years ago. The diameter of the crater is 1.2 km

(photo source: Internet)

Fig.9. Lonar Impact Crater, Maharashtra, India: 1.8km diameter.

(Photo source: Internet)

Is it possible to get "Earth Meteorite" in outer space?

Small pieces of asteroids are hitting our planet everyday without any damage, however if the size of the object is alarmingly large, the impact might be so great that pieces of earth will eject crossing, its escape velocity limit of 11.2km per second and thus producing "Earth meteorite" and that will almost be the doomsday!! Scientists got proof of such an event which occurred 65 million years ago when an object roughly 9.5 km across hit the planet and caused the extinction of almost three-fourth of all land species of life including the dinosaurs. Scientists believe that this event might create "meteorites from Earth".

Fig.10. Impact crater in Salugiri, Tamil Nadu

Fig.11. A piece of meteorite (inset) pierced through tin roof in Katol, Maharashtra

Meteorite Fall and Find

A "fall" is one which is witnessed.

A "find" is not witnessed to fall but found by chance and recognized by diagnostic features.

From the fireballs observation by the Canadian Camera Network, it is estimated that every year about 26,000 meteorites, each weighing above 100 grams, land on earth surface, but most of them are lost in the ocean. It is estimated that extra-terrestrial objects contribute about 10,000 tonnes of material to the earth annually.

As of May, 2013 a total of 45,824 valid meteorites are recorded and another 15,000 are provisionally listed (Source: Meteoritic Bulletin Database), of which only around 1100 are witnessed as observed "fall", rest are "find". Of these reported meteorites, most of the collections are from the cold desert: Antarctica.

Fig.12. A Strange Show in the Sky Over Siberia
(Photo source : Internet)

Fig.13. The main mass of Chelyabinsk meteorite landed in an icy lake near Chebarkul, Russia on 15th February,2013. About 1500 people were injured and >7000 buildings were damaged by the meteorite shower.
(Photo source: Internet)

KAKANGARI

Fig. 14 The meteorite fall occurred in Kakangari, Salem, Tamil Nadu in 1890 featuring circular elevations and depressions due to preservation or removal of chondrules on the dark brown crust

BUTSURA

Location :	Bihar, Champaran, Butsura, 27°07'00" N 84°05'00" E
Date & Time of Fall/Find :	Fall 12- 05-1861 , about noon
Weight (g) & Dimension (cm) of Meteorite fragment :	2134.50 g : 12.5 X 12.0 X 11.5 cm^3
Specific Gravity :	3.60
Classification:	Chondrite

Fig. 15. Butsura meteorite with regmaglypts, rounded edges, flowage of fusion crusts indicating orientation change

DHURMSALA

Location :	Punjab, Kangra, Dhurmsala, 32°14'00" N : 76°28'00" E
Date & Time of Fall/Find :	Fall , 14-07-1860, 14:15:00hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	553.31 g : 9.9 X 6.9 X 6.2 cm^3
Classification:	Chondrite

Fig.16. Convergent fractures define a shatter cone which is characteristic of propagation of shock waves as seen in rocks from impact crater

Record of a meteorite fall, its naming and curating

When a meteorite fall is observed, all the available data are recorded. Most important of which are: date, time and exact location of the fall, the direction of its appearance, the nature of sound and flash of light. Once meteorites are collected, the precise weight of each recovered fragment is recorded.

Meteorites are generally named after the nearest prominent geographical locality, such as Jalangi, Goalpara, Katol etc. In case of a meteorite shower, the nomenclature will be after district of origin (Kendrapara). if meteorites are found far from towns it may be christened after distinct geographic features (Canyon Diablo). In deserts or Antarctica where many meteorites are found in areas with few or no geographic / locality names, meteorite names include abbreviation of a geographic area followed by sample number (ALH84001). A unique name shall apply to the set of all individual bodies recovered from a single observed meteorite fall or meteorite shower. Each individual shall carry the same name as the set.

A new meteorite name must be approved by the international committee on meteorite nomenclature.

Fig.17. GSI meteorite gallery at 15A & B, Kyd Street, Kolkata

In India, Geological Survey of India (GSI) is the sole custodian of all meteorite fall and find within the Indian subcontinent (GSI Meteorite Gallery, Fig.17). Presently GSI is holding nearly 700 meteorites in its possession. Besides, in the gallery of Indian Museum meteorites are in display.

In GSI as well as in museums and universities around the world, scientists responsible for the curation of meteorites take care of classifying new meteorites, storing them for future studies and distributing them to scientists for study. Each gram of meteorite is considered as most valuable matter for scientific research and hence even trivial wastage is unwarranted.

KUTTIPPURAM

Location :	**Kerala, Malabar, Kuttippuram 10˚50'00" N : 60˚02'00" E**
Date & Time of Fall/Find :	Fall 06 04 1914, About 07 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	3,990.50 g : 18.8 X 12.3 X 11.8 cm^3
Specific Gravity :	3.56
Classification:	Chondrite

Fig.18. Dark brown fusion crust with light coloured inner part (broken surface) of Kuttippuram stony meteorite

HARIPURA

Location :	**Rajasthan, Jhunjhunu, Haripura 28˚23'00" N : 75˚47'00" E**
Date & Time of Fall/Find :	Fall 17 01 1921, 21 00 00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	279.76 g : 8.1 X 7.1 X 4.8 cm^3
Specific Gravity :	2.76
Classification:	Chondrite

Fig.19. A few circular pores, deep and without any spallation zone, possibly due to escape of gases

How to identify a Meteorite?

The most important identification tool of meteorite are its heaviness because of its higher specific gravity than most terrestrial rocks and brown to deep brown or black coloured fusion crust (Fig.18-21) on the outer surface of fresh meteorites.

Meteorites are usually devoid of some minerals which are common in our planetary rocks such as quartz, carbonates, mica etc. However in some rare and special type of meteorite these minerals are also present. Terrestrial rocks have specific gravity ranging from 2.6 to 3.0 and the meteorites have the specific gravity generally in the range 3.0 to 3.7. Some meteorites have low specific gravity (<3.0), but such are rare. Iron meteorites are very dense having specific gravity 7-8.

BORI

Location :	**Madhya Pradesh, Betul, Bori, 21°57'00" N : 78°02'00" E**
Date & Time of Fall/F	Fall 09-05-1894
Weight (g) & Dimension (cm) of Meteorite fragment :	4911.19 g : 17.0 X 15.0 X 9.6 cm^3
Specific Gravity :	3.45
Classification:	Chondrite

Fig. 20. Nature of fusion crust indicates two stages of fragmentation

MIRZAPUR

Location :	**Uttar Pradesh, Ghazipur, Mirzapur, 25°41'00" N : 83°15'00" E**
Date & Time of Fall/Find :	Fall 07 01 1910, 11 30 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	7932.10 g (in 2 pieces) 23.4 X 16.0 X 12.0 cm^3
Classification:	Chondrite

Fig. 21. Fusion crust on the irregular faces is warty and fractured

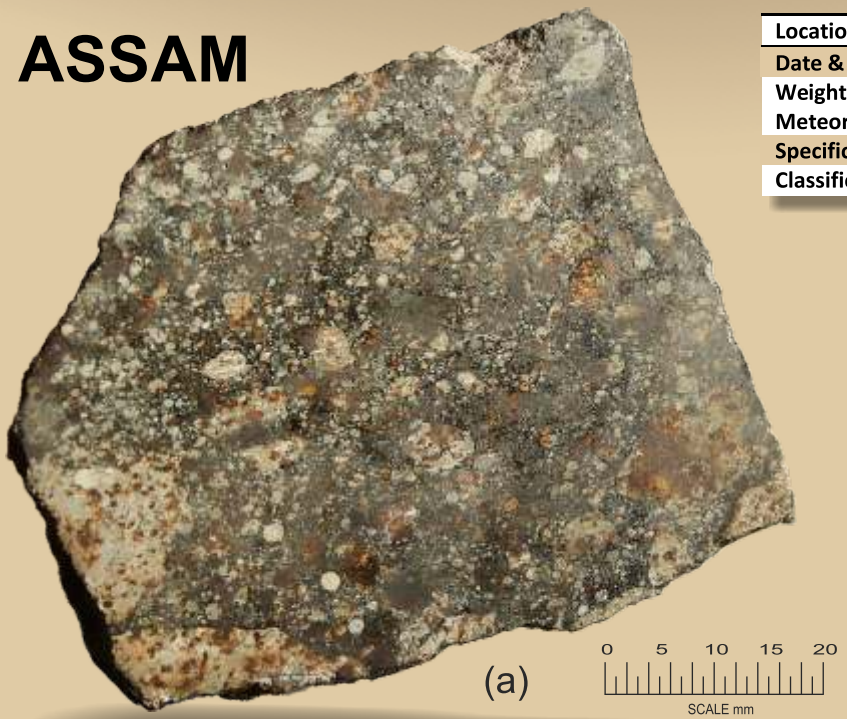
The fused surface is the most characteristic feature to identify a meteorite. During transit through earth atmosphere due to 'frictional' heating outer surface of the rock melts and this **fusion crust** (Fig.18-21) develops. Most meteorites are polygonal; the faces may be flat or curved (concave, convex or concavo-convex) (Fig. 5, 15). The nature of edges may be well rounded to rounded (Fig. 5, 23) due to prolonged ablation or sharp due to less ablation. Because of friction and heat, sometimes the molten upper surface left a trail mark as **flow lines** (Fig.25, 27) or indentations like thumb prints which is called **regmaglypts** (Fig. 23, 28,). Such depressions are of various sizes and shape. They may be almond-shaped, polygonal, narrow, elongated, fissure-like; they may be single and discrete or compound, when more than one mutually ragmaglypts occur within a large ragmaglypts.

Incidence of specks of **iron-nickel metal** and sometimes presence of small circular grains, termed as **Chondrules** are convincing characteristic of a meteorite.

However, many a meteorite fragments may be found without any of these characters, making them apparently difficult to distinguish from terrestrial rocks. This is one of the very specialized subject and any such suspected sample should be brought to the notice of a meteoriticist.

ASSAM

Location :	**Assam, 26˚00'00" N: 92˚00'00"E**
Date & Time of Fall/Find :	Find 1846, Date & Time: unknown
Weight (g) & Dimension (cm) of Meteorite fragment :	289.90 g : 6.7 X 5.2 X 4.0 cm^3
Specific Gravity :	3.79
Classification:	Chondrite



BUTSURA

Location :	**Bihar, Champaran, Butsura, 27°07'00" N 84°05'00" E**
Date & Time of Fall/Find :	Fall 12- 05-1861 , about noon
Weight (g) & Dimension (cm) of Meteorite fragment :	2134.50 g : 12.5 X 12.0 X 11.5 cm^3
Specific Gravity :	3.60
Classification:	Chondrite

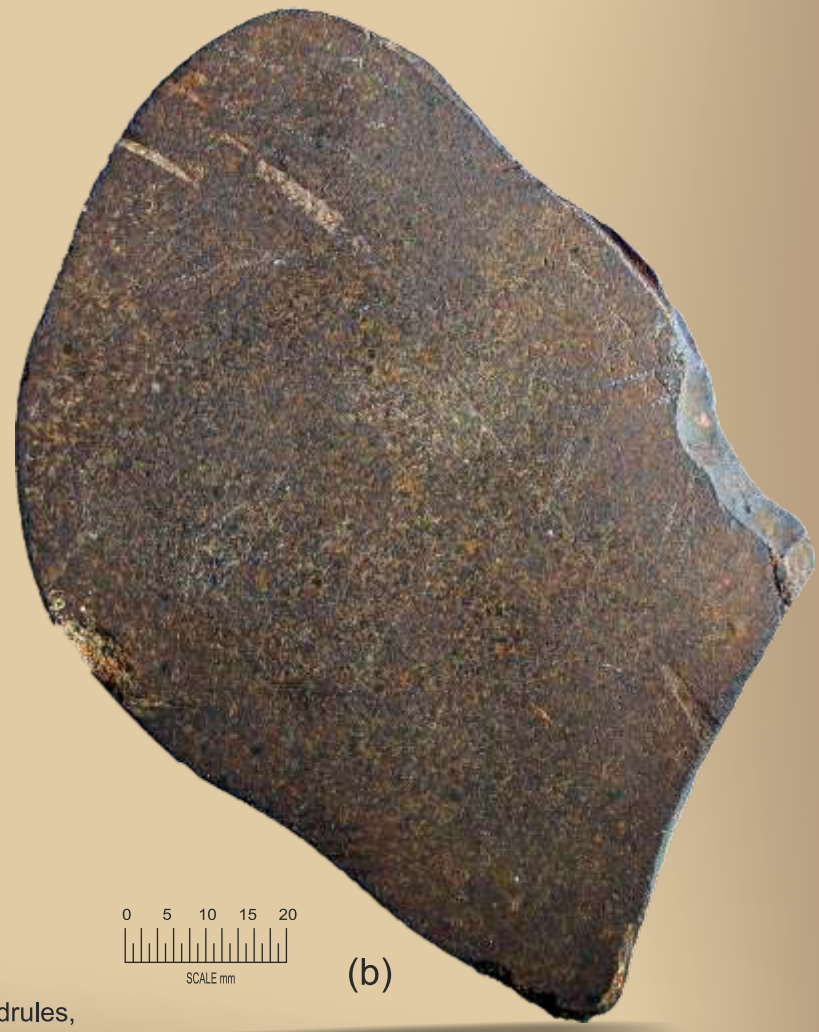


Fig.22. Cut face of meteorites with a) large chondrules b) small chondrules,

LUA

Location :	**Rajasthan, Udaipur, Lua, 24°57'00" N ; 75°09'00" E**
Date & Time of Fall/Find :	Fall 26-06-1926, 16: 00: 00 Hrs.
Weight (g) & Dimension (cm) of Meteorite fragment :	8627.00 g : 22.5 X 16.0 X 11.1 cm^3
Specific Gravity :	3.53
Classification:	Chondrite

Fig.23. Rounded edges and ripples with linear crests and troughs in Lua meteorite

ERAKOT

Location :	**Madhya Pradesh, Jagadalpur, Erakot, 19˚02'00"N : 81˚53'30" E**
Date & Time of Fall/Find :	Fall 22 06 1940 17 00 00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	91.16 g : 6.2 X 4.6 X 4.5 cm^3
Specific Gravity :	2.66
Classification:	Chondrite

Fig. 24. Scoriaceous texture on the basal face represents the front while the apex of the pyramid indicates the front in course of its flight

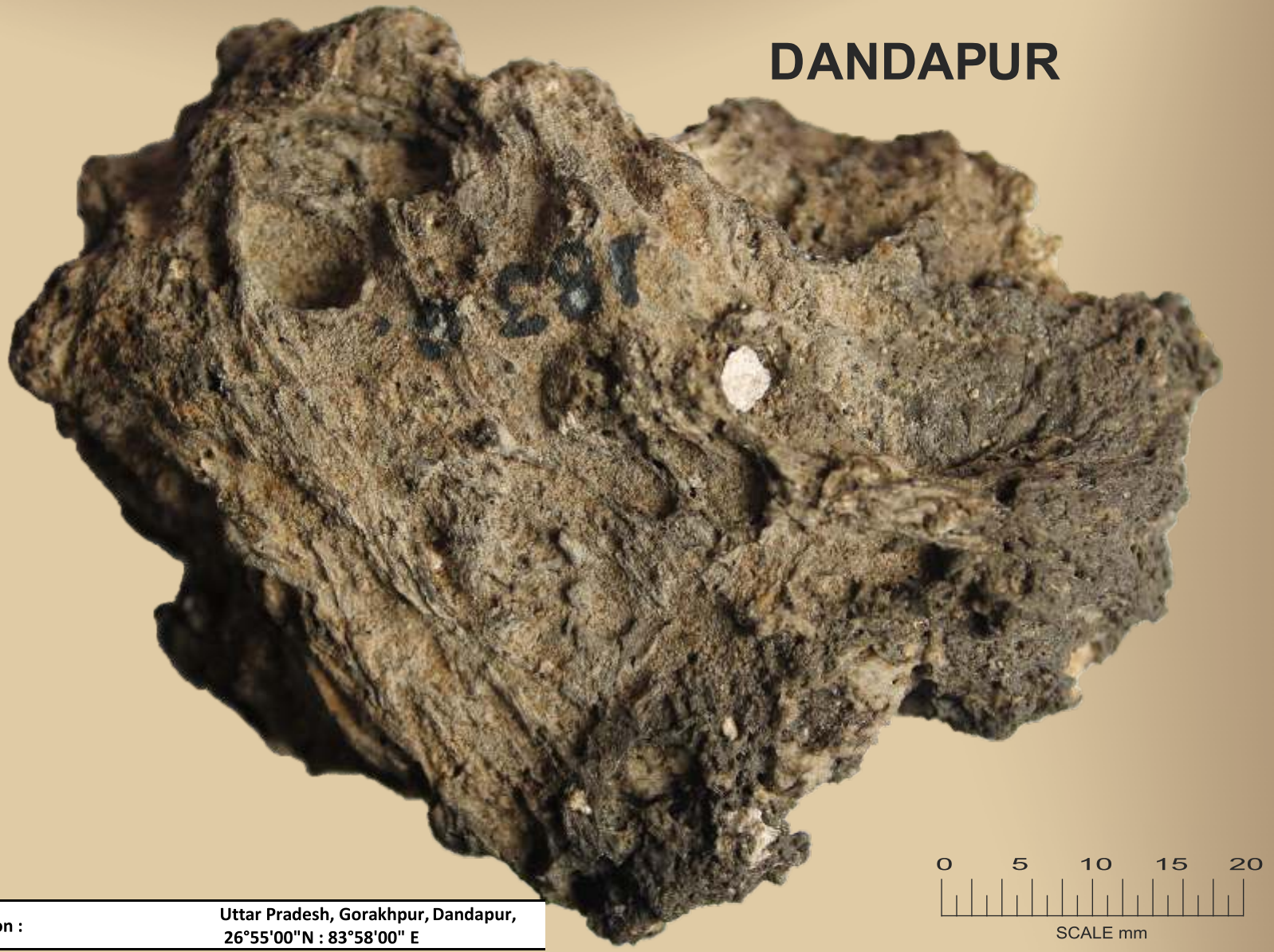
KASAULI

Fig.25. Flow lines originating from front (stagnation point) and continuing downward in Kasauli stony meteorite, Muzaffarnagar, 2003, U.P.

MUDDOOR

Location :	Karnataka, Mysore, Muddoor, 12˚38'00" N : 77˚01'00" E
Date & Time of Fall/Find :	Fall 21 09 1865, 07 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	1518.12 g : 12.4 X 9.5 X 7.0 cm^3
Classification:	Chondrite

Fig.26. Well rounded with innumerable chondri; scoriaceous fusion crust



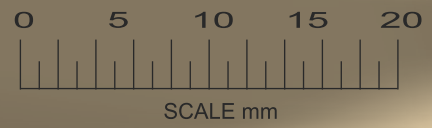
Location :	**Uttar Pradesh, Gorakhpur, Dandapur, 26°55'00"N : 83°58'00" E**
Date & Time of Fall/Find :	Fall 05-09-1878, 17-00-00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	1572.45 g : 9.9X9.5X9.2 cm^3
Specific Gravity :	3.29
Classification:	Chondrite

Fig.27. Contorted flow lines/ribs on a meteorite surface

FUTTEHPUR

Fig.28. Regmaglypts

Location :	**Uttar Pradesh, Allahabad, Futtehpur, 25°57'00" N : 80º49'00" E**
Date & Time of Fall/Find :	Fall 30-11-1822, 18: 00: 00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	717.38g : 9.0 X 5.0 X 5.0 cm^3
Classification:	Chondrite



ATARRA

Location :	**Uttar Pradesh,Banda, Atarra, 25˚15'09" N: 80º37'00" E**
Date & Time of Fall/Find :	Fall 23-12-1920, 17:35:00 hrs.
Weight (g) & Dimension (cm) of Meteorite fragment :	595.45 g : 11.6 X 8.9 X 6.0 cm^3
Specific Gravity :	3.48
Classification:	Chondrite

Fig.29. Almond shaped regmaglypts

DELHI

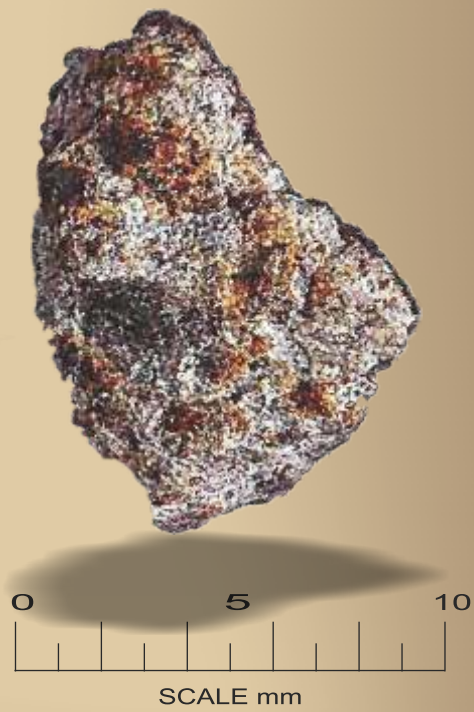


Fig.30. Chondri in recrystallised matrix of Delhi meteorite fell in 1897

Meteorite Classification

The broad classification of meteorites into stony, iron and stony-iron types is based on the amount of silicate minerals and iron metal in the meteorite. However, detail classification of meteorites is complex and each of these major groups of meteorite is further subdivided on the basis of mineralogical and chemical composition, texture.

Stony meteorites are composed dominantly of silicate minerals and are further texturally subdivided into chondrites and achondrites.

Meteorite Composition

Meteorites are objects of great scientific interest, not only on account of their rarity, but also of their composition and structure. They are the only tangible source of our knowledge of the universe around our earth, being actually portions of extra-terrestrial bodies.

Stony meteorites are composed of a variety of minerals. Most of the minerals are available in Earth rocks, but in different proportion. A few rare minerals are found only in meteorites.

Iron meteorite is similar in composition to that of core of the Earth. Different types of meteorites have different types and proportions of minerals and different compositions. Therefore, meteorites are classified by their mineralogy and composition. The ultimate goal of meteorite classification is to group together all specimens that share a common origin on a single identifiable parent body.

Native elements present in meteorites are diamond, graphite and various alloys of nickel-iron, kamacite, plessite and taenite. The most common silicate minerals are olivine (Fe-Mg-silicate), pyroxene (Fe-Mg-Ca silicate), feldspar (Na-Ca-K-Al silicate); varying amount of metallic Iron (Fe) and Nickel (Ni) and Iron Sulphide (Fe-S). Magnetite and chromite are the commonest oxides, merrillite the phosphate.

AT A GLANCE

Near Earth Object (NEO) - Near Earth Objects are asteroids or comets that have orbits around the Sun that bring them close to the Earth. The actual definition of an NEO is a comet or asteroid whose orbit brings it close to Earth's orbit.
Asteroid - A relatively small, inactive body, composed of rock, carbon or metal, which is orbiting the Sun.
Comet - A relatively small, sometimes active object, which is composed of dirt and ices. Comets are characterised by dust and gas tails when in proximity to the Sun. Far from the Sun it is difficult to distinguish an asteroid from a comet.
Meteoroid - A small particle from an asteroid or comet orbiting the Sun with size limit between 100 micrometre and 10 metre across.
Meteor - A meteoroid that is observed as it burns up in the Earth's atmosphere – a shooting star.
Meteorite - A meteoroid that survives its passage through the Earth's atmosphere and impacts the Earth's surface.

In summation, an asteroid is a relatively small object out in space. When an asteroid breaks through our atmosphere and burns up, it becomes a meteor. If the asteroid manages to get all the way through our atmosphere and actually hits the surface of the planet, it is classified as a meteorite.

CRANGANORE

Location :	**Kerala, Ernakulam, Cranganore, 10˚11'00" N : 76˚16'00"E**
Date & Time of Fall/Find :	Fall 03 07 1917, 12 45 00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	715.27 g : 9.0 X 8.0 X 7.3 cm^3
Specific Gravity :	3.47
Classification:	Chondrite

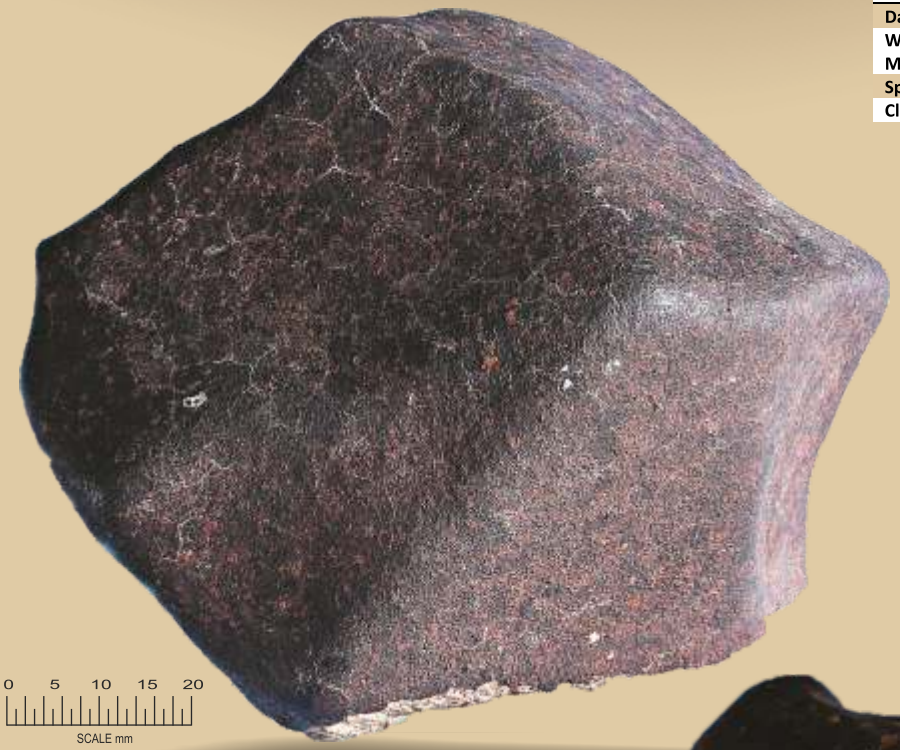


Fig.31. Cranganore Stony
Meteorite characterises rounding edges

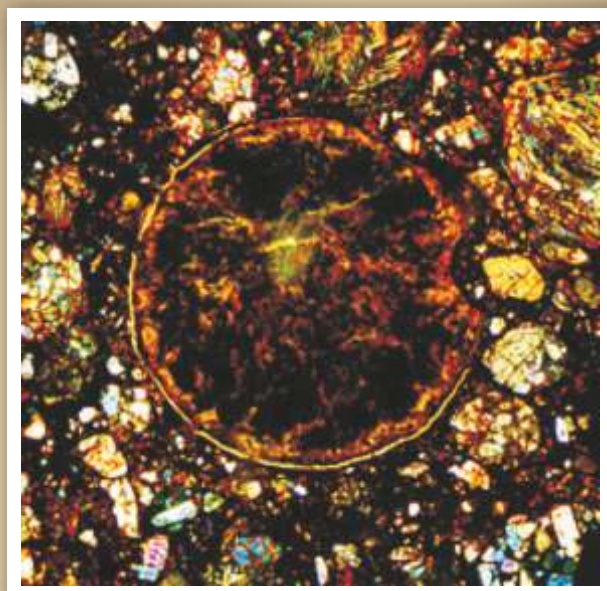
MUZAFFARPUR

Location :	**Bihar, Bahrampur, Muzaffarpur, 26˚08'00" N : 85˚32'00"**
Date & Time of Fall/Find :	Fall 11 04 1964, 17 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	985.00 g : 13.2 X 7.0 X 6.2 cm^3
Specific Gravity :	8.14
Classification:	Iron Mereorite (Plessitic Octahedrite (Opl), Iranom, 12.9)

Fig.32. Muzaffarpur Iron Meteorite

Chondrites

Photomicrograph of chondrules
(small circular features)



BISHUNPUR

Chondrules
in hand specimen

Location :	**Uttar Pradesh, Mirzapur, Bishunpur, 25˚23'00" N : 82˚36'00"E**
Date & Time of Fall/Find :	Fall 26 04 1895 , 15 00 00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	275.27 g : 7.0 X 4.5 X 3.7 cm^3
Specific Gravity :	3.30
Classification:	Chondrite

Fig.33. Chondrules in chondrites of Bishunpur meteorite

Chondrites, named after the tiny pellets of rock called "chondrules" (Fig.33) embedded in them, a result of a kind of chemical fractionation unique to small bodies, contain chondrules.

About 90% of meteorite 'fall" and most of the Antarctic meteorites are chondrites making them the most abundant type of extra terrestrial bodies. They probably came from parent bodies that were too small to undergo a large degree of gravitational differentiation, or are collision ejecta from less than catastrophic collisions of slightly differentiated bodies. These are easily identifiable non-terrestrial object.

ANKHEDIYA MOTA

Location :	**Gujarat, Panchmahal, Ankhediya mota, 22°21'20" N: 73°34'30" E**
Date & Time of Fall/Find :	Fall 02-09-1985, 11:45:00 hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	1286.56 g : 14.5 x 11.8 x 7.0 cm3
Classification:	Chondrite

Fig.34. Chondri are moderate to weakly integrated in a fragile fine grained crystalline dirty white matrix

SEGOWLIE

Location :	**Segowlie ,Champaran , Bihar 26°45'00" N 84°47'00" E**
Date & Time of Fall/Find :	Fall 04 03 1853, 12 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	3435.11 g: 14.0 X 14.0 X 12.5 cm^3
Specific Gravity :	3.42
Classification:	Chondrite

Fig.35. Chondrules loosely integrated with the matrix, flowage of the fusion crust

BHERAI

Fig. 36. Anastomosing veins filled with brownish material terminating fusion crust can be seen in meteorite fell at Bherai, Junagarh, Gujarat in 1893

NAOKI

Location :	**Naoki, Parbhani, Maharashtra, 19°15'00" N : 77°00'00" E**
Date & Time of Fall/Find :	Fall 29 09 1928, 17:00: 00 Hrs.
Weight (g) & Dimension (cm) of Meteorite fragment :	4962.06 g : 14.0 X 12.7 X 9.1 cm^3
Specific Gravity :	3.70
Classification:	Chondrite

Fig.37. Ribbed to netted textures along the edge of the regmaglypts

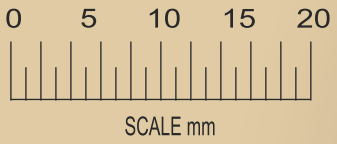
Chondrites are further subdivided into several classes, of which **carbonaceous chondrites,** are the most important and rare type of meteorite. These contain carbon (including organic carbon) compound and water which are not reported in any other types of meteorite. Being most primitive type, carbonaceous chondrites retain the character acquired more than ~4.56 billion years ago, i.e, before the birth of the Earth. This uniqueness makes them potential to divulge the earliest history of the solar system as well as the possible trail from which life might have evolved.

Ordinary chondrite are also very important group to understand the history of evolution of the solar system.

CHANDPUR

Mainpuri, Uttar Pradesh,
fall: 04.06.1885

Fig. 38. Veined chondrite with shallow regmaglypts,



CHANDAKAPUR

Buldana in Maharashtra,
fall : 06.06.1838

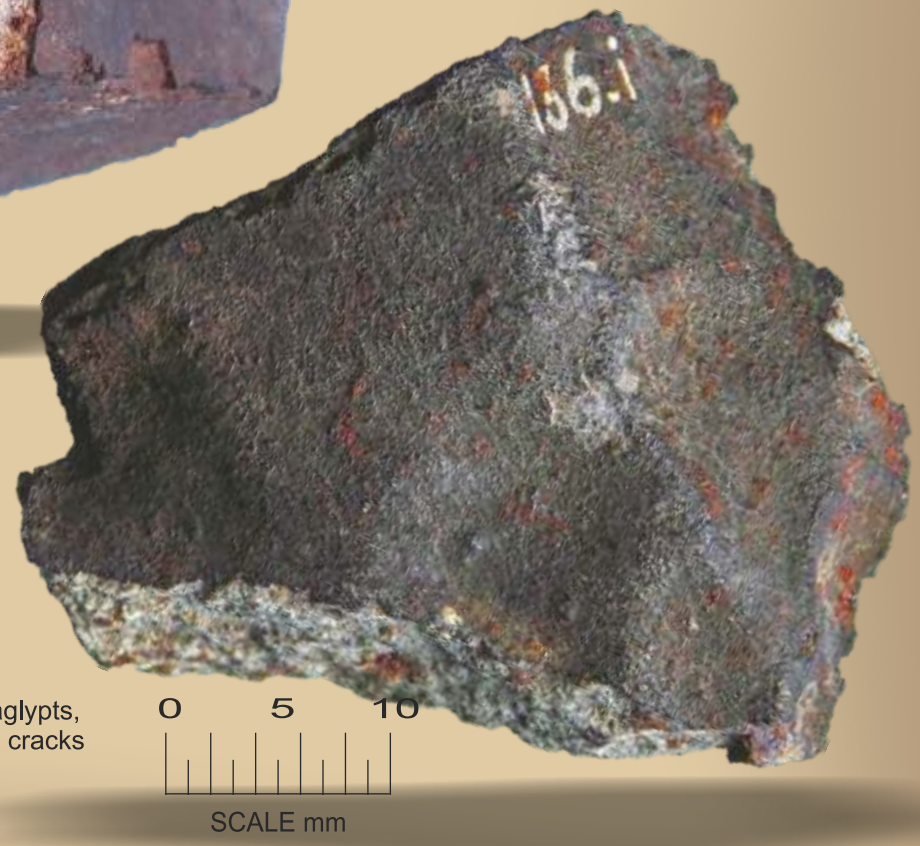


Fig. 39. Compound regmaglypts, prominent ribs, knobs and cracks

RANGALA

Location :	**Rajasthan, Jodhpur, Rangala, 25°23'00" N 72°21'00"E**
Date & Time of Fall/Find :	Fall 29-12-1937, 10:00:00 Hrs.
Weight (g) & Dimension (cm) of Meteorite fragment :	531.06 g : 8.7 x 7.0 x 6.2 cm^3
Specific Gravity :	3.62
Classification:	Chondrite

Fig.40. Abundant grey rounded to subrounded chondri, knobs, ribs and locally scoriaceous, flowage of fusion crust

POKHRA

Location :	**Uttar Pradesh, Basti, Pokhra, 26˚43'00" N : 82˚40'00 " E**
Date & Time of Fall/Find :	Fall 27 05 1866,20 30 00 Hrs.
Weight (g) & Dimension (cm) of Meteorite fragment :	217.65 g : 5.0 X 4.5 X 4.4 cm
Classification:	Chondrite

Fig.41. Scoriaceous and knobby fusion crust

How does a meteorite (Chondrite) look under microscope?

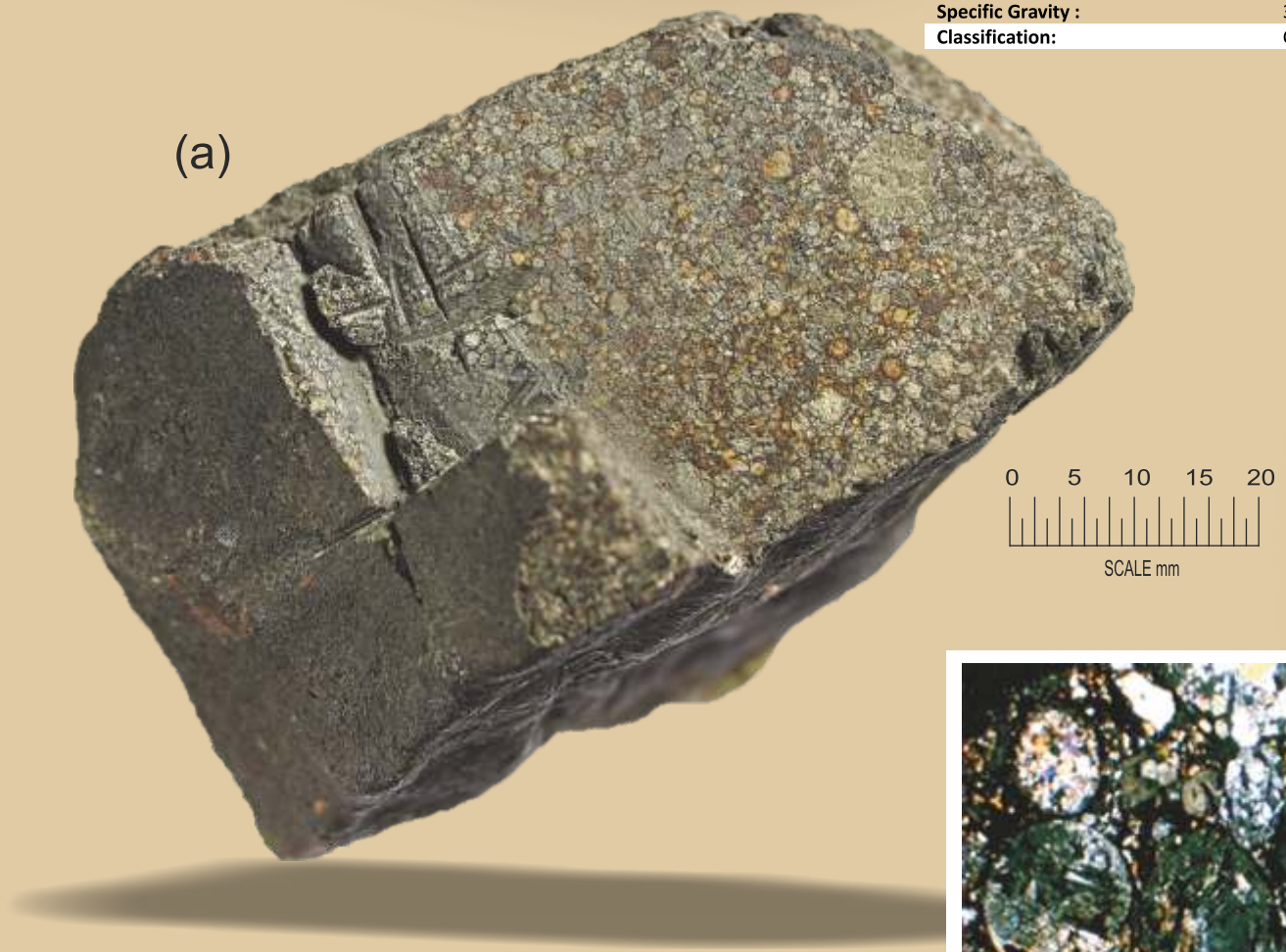
In Fig.42(b), the distinct circular chondrules are made of minerals like olivine (Fe-Mg silicate) and pyroxene (Ca-Fe-Mg silicate) which are set in a fine grained matrix, of same constituents. Clasts and fragments of olivine and pyroxenes are also present.

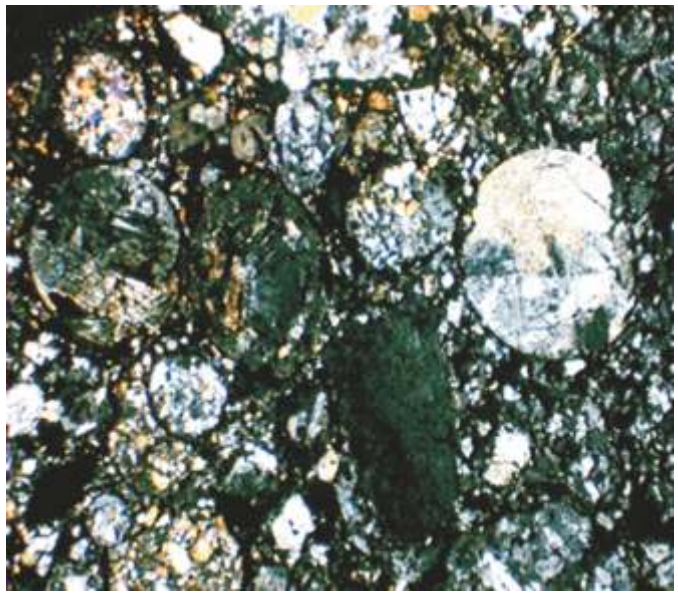
In Fig.43, the chondrule is glassy in composition (a) and the barred olivine chondrule (b) is composed of alternate olivine and glass (a mixed composition of Na-Al- Fe-Mg silicate), the bright phases are Fe-Ni metal

SEMARKONA

Location :	**Madhya Pradesh, Chindwara, Semarkona, 22˚15'00" N : 7˚00'00"E**
Date & Time of Fall/Find :	Fall 26 10 1940, Time not known
Weight (g) & Dimension (cm) of Meteorite fragment :	368.80 g : 8.0 X 6.4 X 4.0 cm^3
Specific Gravity :	3.46
Classification:	Chondrite

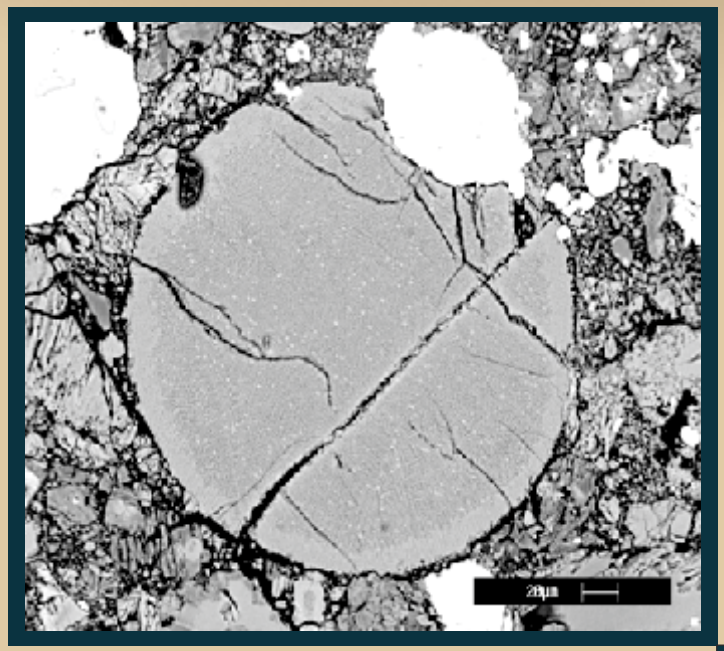
(a)



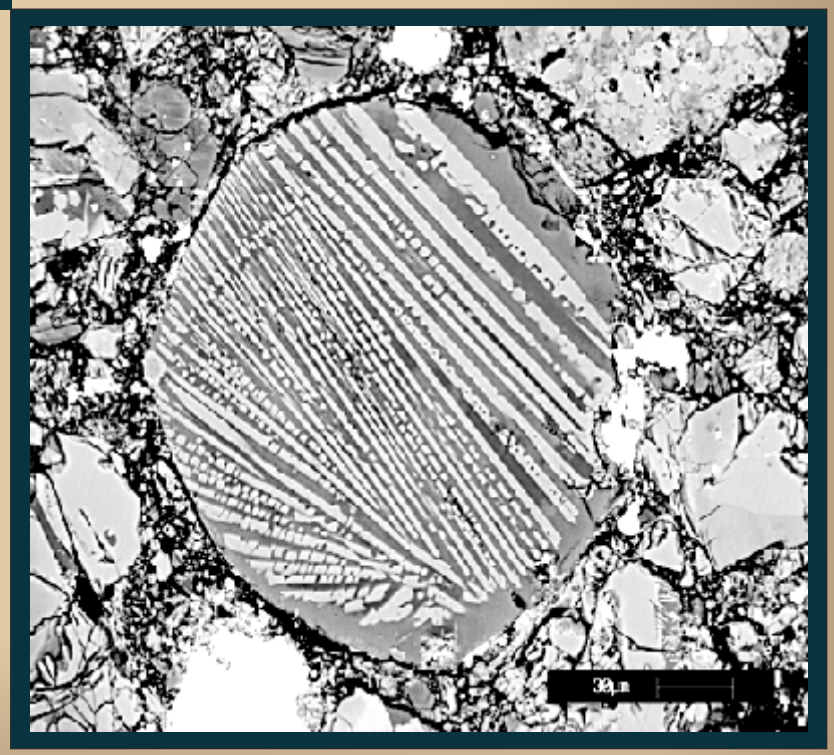


(b)

Fig. 42. Typical chondrite exhibiting chondrules in (a) sample and (b) thin section under microscope



(a) Back Scattered Electron (BSE) Image of a glassy chondrules (Semarkona Chondrite)



(b) Back Scattered Electron (BSE) Image of a barred olivine chondrule (Bishunpur Chondrite)

Fig. 43. Back Scattered Electron (BSE) Image


Achondrite

Achondrites are coarsely crystallised silicate rich stony meteorites devoid of chondrules. These are further classified into different groups on the basis of composition, texture and sometimes by isotopic characters.

These meteorites are evolved from chondrites and hence younger than parent chondrite.

Achondrites are the result of gravitational differentiation in relatively large bodies by melting and gravitational separation of mineral phases, and most resemble the Earth's crust.

Achondrites include the planetary meteorites (Martian or Lunar). Shergotty achondrite (Fig.5) weighing >3.5kg fell on 25.08.1865 at Shergotty, Gaya, Bihar. In late 1970's, after interpretation of data by Viking Mission, NASA, this Indian meteorite was confirmed as an Martian Achondrite. Meteorites of similar composition are grouped as Shergottites. These are mafic igneous rocks resembling terrestrial basaltic rock.

GOALPARA

Location :	**Assam, Goalpara, 26˚03'00" N 90˚40'00" E**
Date & Time of Fall/Find :	Fall 1968, Date & Time unknown
Weight (g) & Dimension (cm) of Meteorite fragment :	421.03 g : 7.6 X 7.0 X 6.9 cm^3
Classification:	Ureilite Achondrite

Fig. 44. The conical face exhibits numerous larger and deeper almond shaped regmaglypts arranged in a radial fashion pointing towards the base; flowage of fusion crust across the edge. High degree of maturity of the conical face suggests a longer travel time.

HARAIYA

Location :	**Uttar Pradesh, Basti, Haraiya, 26˚48'00"N : 82˚32'00" E**
Date & Time of Fall/Find :	Fall August or September, 1878 , Date unknown, Afternoon
Weight (g) & Dimension (cm) of Meteorite fragment :	493.21 g : 8.6 X 7.8 X 5.7 cm^3
Specific Gravity :	3.19
Classification:	Eucrite Achondrite

Fig. 45. Prominent radiating streaks on the hemispherical half fusion crust, the frontal part during travel time

SHALKA

Location :	**West Bengal, Bankura, Shalka, 23˚06'00" N : 87˚18'00" E**
Date & Time of Fall/Find :	Fall 30-11-1850, 16-30-00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	1351.82 g : 13.4 X 10.0 X 7.5 cm^3
Specific Gravity :	3.41
Classification:	Diogenite Achondrite

Fig. 46. A high degree of brecciation forming monomict breccia; highly abladed

LAKANGAON

Location :	**Madhya Pradesh, Nimar, Lakangaon, 21˚52'00" N : 76˚02'00" E**
Date & Time of Fall/Find :	Fall 24 11 1910, 18 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	56.13 g : 4.4 X 3.2 X 2.8 cm^3
Classification:	Eucrite Achondrite

Fig. 47. Loss of volatiles due to melting during the flight produces fine porosity in between nets on the crust

Iron Meteorite

MUZAFFARPUR

Location :	**Bihar, Bahrampur, Muzaffarpur, 26˚08'00" N : 85˚32'00"**
Date & Time of Fall/Find :	Fall 11 04 1964, 17 00 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	985.00 g : 13.2 X 7.0 X 6.2 cm^3
Specific Gravity :	8.14
Classification:	Iron Mereorite (Plessitic Octahedrite (Opl), Iranom, 12.9)

Fig.48. The fragment shows a high degree of ablation attaining the rounding of faces; thicker fusion crust along the edges of the convex face; the flowage pattern depicts the convex face in the front initially but later on occupied the rear position possibly after fragmentation

Iron meteorites, also called "irons", are usually just one big blob of iron-nickel (Fe-Ni) metal, as if it came from an industrial refinery without shaping. It makes up only 5% of meteorite falls.

The composition of Iron meteorites is strikingly similar to that of the core of our planet. Iron meteorite, as its name implies, consists almost entirely of native iron (Fe) and nickel (Ni). Nickel percentage may range from less than 5% up to about 30%. Depending upon the proportion of iron and nickel and certain trace elements viz., Ga, Ge and Ir, iron meteorites are grouped into several classes.

When a polished surface of an iron meteorite is etched, a well marked minute structure is generally brought out. On the majority of iron meteorites, widmanstatten structure is formed by high and low nickel rich bands (Fig.52).

KODAIKANAL

Location :	**Tamilnadu, Madurai, Kodaikanal, 10˚16'00" N : 77˚24'00" E**
Date & Time of Fall/Find :	Find 1898, Probably fell on 1890
Weight (g) & Dimension (cm) of Meteorite fragment :	572.64 g : 11.2 X 4.9 X 3.4 cm^3
Specific Gravity :	7.29
Classification:	Finest Octahedrite

Fig. 49. The convexity of the face refers to more ablation and possibly the frontal part in comparison to other faces of the boat shaped fragment; close textured with few knobs and ribs and peeled off at many places.

RAGHUNATHPUR

Location :	**Rajasthan, Alwar, Raghunathpur, 27°43'31" N : 76°27'54" E**
Date & Time of Fall/Find :	Fall 20 11 1986 , 20 10 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	10,130.00 g : 16.8 X 15.5 X 8.5 cm^3
Specific Gravity :	7.60
Classification:	Iron Meteorite (Hexahedrite (H), IIA, 4.98)

Fig. 50. Fine streaks of radiating flowage on fusion crust of rounded edge

SAMELIA

Location :	**Rajasthan, Bhilwara, Samelia, 25°40'00" N : 74°52'00" E**
Date & Time of Fall/Find :	Fall 20 05 1921, 17 30 00 Hrs
Weight (g) & Dimension (cm) of Meteorite fragment :	1009.40 g : 11.0X 9.4 X 4.5 cm^3
Specific Gravity :	7.83
Classification:	Iron Meteorite

Fig. 51. Triangular fragment with distinct elongated, compound, deep regmaglypts

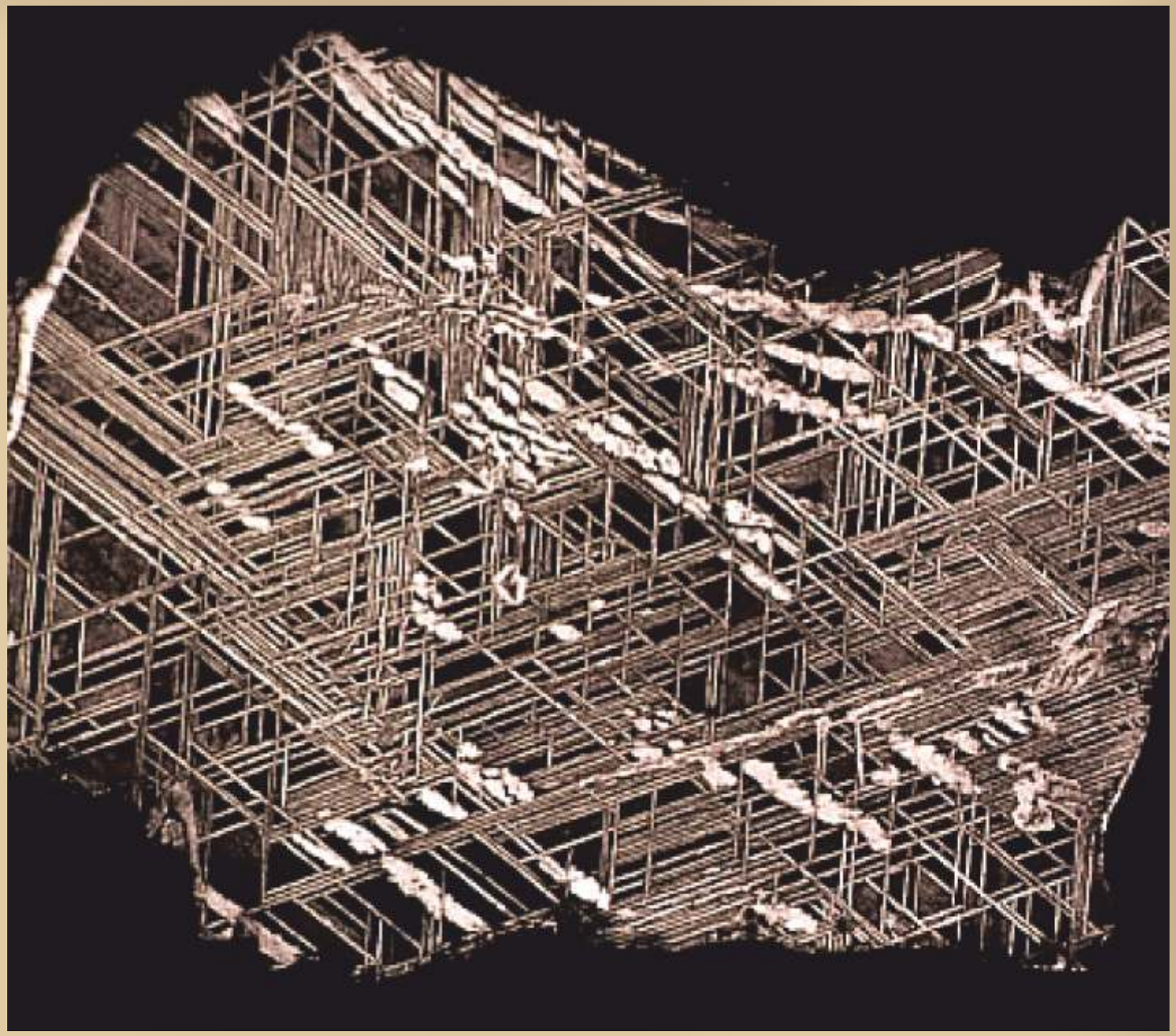


Fig. 52. A polished and etched surface of an iron meteorite with widmanstatten structure produced by bands of high and low Ni rich bands.

(Photo source: Internet)

Stony Iron Meteorites

It consists of mixtures of Fe-Ni metal of between 30% and 70% along with mixtures of various silicates and other minerals. The Fe-Ni metal can be present as chunks, pebbles and granules. Stony iron meteorites resemble the outer cores or mantles of planetoids or else a mix of materials due to a collision.

These are rare type of meteorites having only two main groups viz. Pallasites and Mesosiderites. Pallasites (Fig.53), one of the most attractive meteorites, are mixtures of stony mineral olivine (peridot) and iron-nickel metal. Mesosiderites are mainly composed of angular fragments of basaltic achondrite and pieces of Fe and Ni metals.

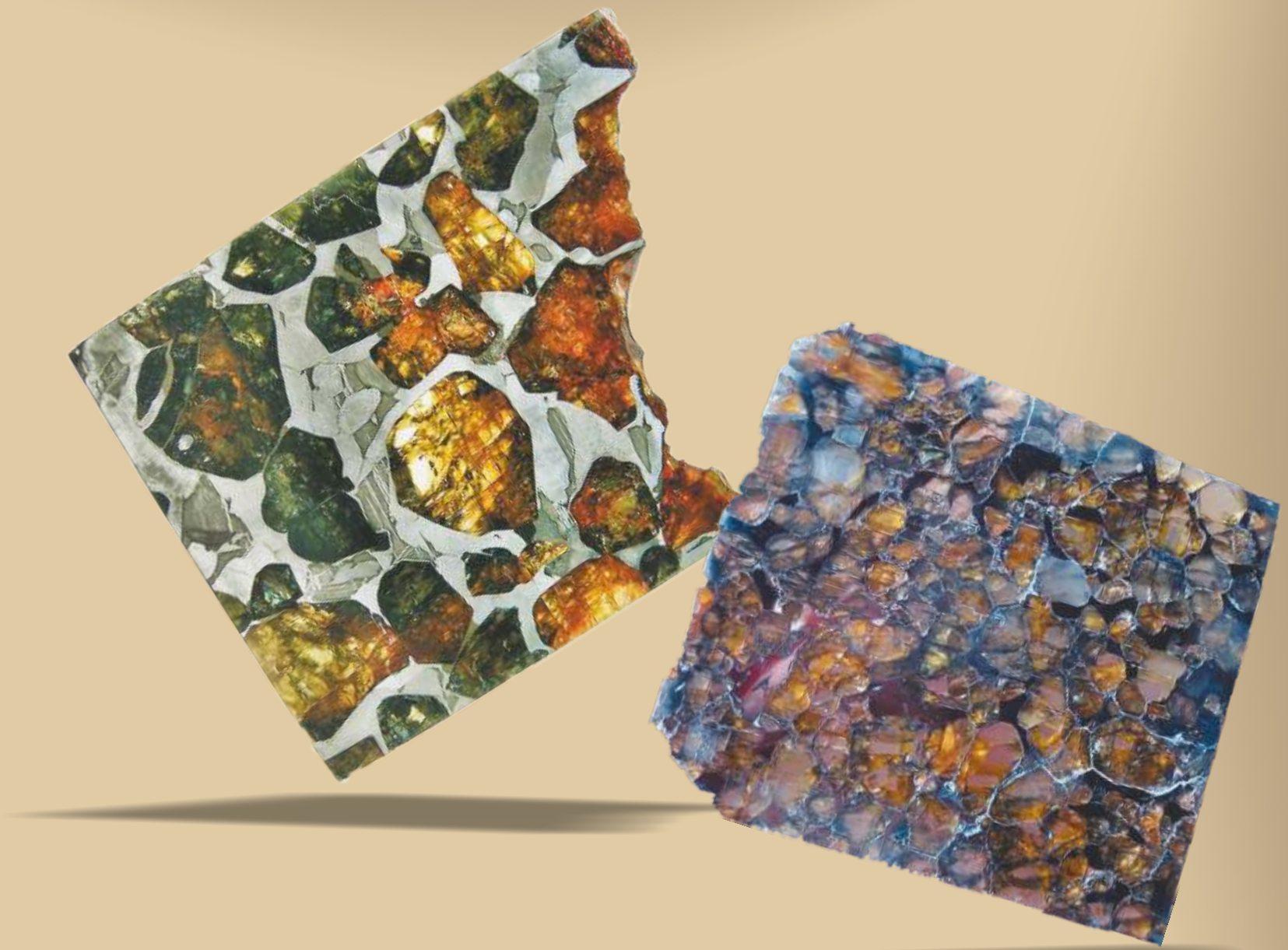


Fig. 53. Polished slices of pallasites. (Photo source: Internet)

Origin of Meteorites

Indian Meteorite

The most valuable planetary rock specimens available on the Earth are meteorites. Till date, any manned or unmanned space mission has not got it. Thus the study of meteorites gives glimpses of diversion array of planetary material scattered in our solar system.

The earliest meteorite specimens represent the first geological processes to occur in our solar system 4.6 billion years ago.

This solar system formed when a cloud of interstellar dust and gas collapsed. This slowly spinning interstellar cloud formed a near-flat rotating disk, referred to as solar nebula. Much of the gas and dust moved to the centre of the nebula to feed the growing protostar which eventually became a star.

Scientists believe that condensation of the remaining gas–dust clouds in pre-solar nebula gave rise to small cosmic dust balls which in some regions of solar nebula encountered violent high temperature events. These dust balls were melted by some large scale heating event like shock waves / collision or solar flare or nebula lightning. Subsequent quick cooling of thus formed high temperature silicates and metals droplets produced millimetre-sized spheres of rocks called chondrules. Meteorites containing these objects are called chondrites.

Different chondrules, floating in space, accreted with other chondrules and cosmic dust, forming Chondrite Parent Body (CPB).

Fig. 54. Halley's Comet as it appeared in February 1986, Anglo-Australian Observatory/Royal Observatory.

CPB represents primordial mixtures of silicate minerals, metals, sulphides and the oldest pre-solar objects like Ca-Al-inclusions (CAI) or white inclusions.

CPB were subjected to heating in different magnitudes because of probable in situ radioactivity and also collision with other chondrites. This heat was not enough to melt those were / are preserved as chondritic asteroid / meteorites body. These parent bodies were also not large enough to generate sufficient heat to melt. As such retained as original accreted primordial solar objects.

Most stony meteorites and all carbonaceous meteorites are chondrites. These rocks are primeval fragments of the solar system's original mineral grains. Dating by the technique of radioactive decay shows that the most primitive meteorites formed during a "brief" interval of only 20 million years, some 4.6 billion years ago.

Other types of radioactive dating show that major of collisions among these bodies happened throughout the interval from 4.6 to about 4.4 billion years ago. Thus chondrites are 4.4-4.6 billion years old, most primitive objects formed at the dawn of the solar system.

All other meteorites viz., achondrites, irons, and stony-irons are differentiated products formed by igneous processes and changed by impacts and metamorphism.

However, due to this heat, they experienced significant thermal metamorphism, involving creation of different petrologic types of chondrites.

Large chondritic bodies are subjected to enough heat, which produced melt of constituting primordial mixtures.

The heating mechanisms are unknown; maybe it was concentrations of radioactive minerals, magnetic or electrical effects, or shock waves - all these sources have been suggested.

Whatever is the heat source, the iron meteorites and stony-iron mixtures show that some asteroids differentiated completely. Dense heavier Fe-Ni rich liquid settled by gravity to form core of mini planet, parent body of iron meteorites. By process of differentiation, lighter silicate part solidified in upper part, forming achondrites.

At late stage of melting process cooling, contraction and cracking in overlying silicate (olivine rich) mantle, led to injection of molten metal upward which solidified to form a mesh enclosing silicates, forming stony-iron meteorites.

Violent impact-collisions among such differentiated asteroids separated various types of Nonchondritic Meteorites.

Epilogue

Sporadic collisions continued to smash other asteroids together with one another and with planets throughout solar system.

Such happenings are much safer today than they were in the earliest days of our solar system.

While asteroids continue to attack, we have no reason to fear planet destroying object will wreck any near-future tomorrows.